Åkerneset – the threat from an unstable rock slope in Storfjorden, western Norway: A review of research and civil protection issues

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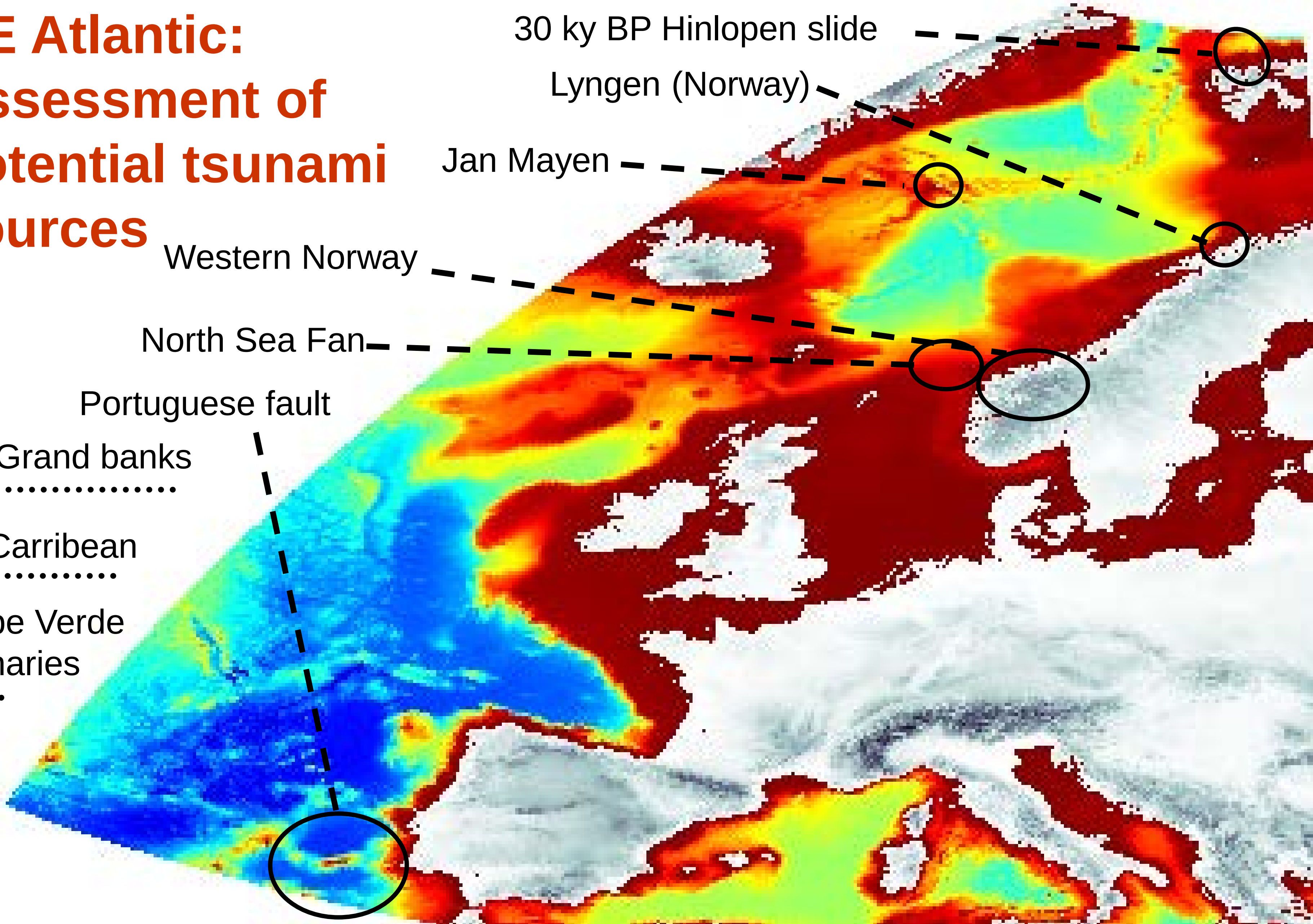
PARI-METU-NGI RAPSODI field trip to Åkerneset September 5 2014

NE Atlantic: Assessment of potential tsunami sources



NE Atlantic tsunami hazard – Summary of tsunamigenic potential

Seismic sources north of the British Isles – not critical

Jan Mayen volcanic source – not critical

Hinlopen – not critical

Arctic Ocean, Iceland, Greenland, Svalbard and Bear Island Fan – not studied

Grand Banks, Cape Verde, Caribbean – not critical

Portuguese faults (impact on British Isles) – moderately critical

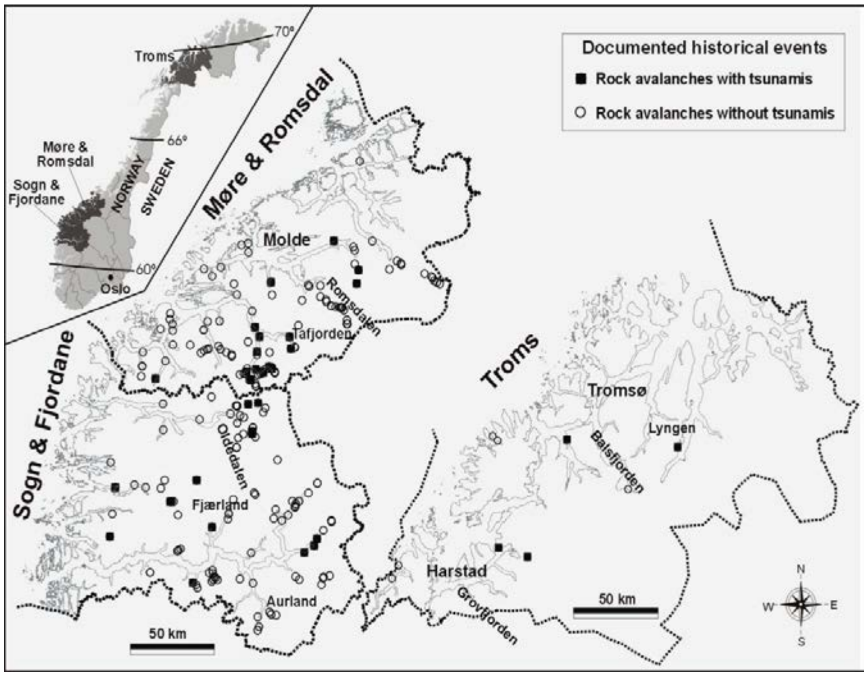
North Sea Fan (Norway, British Isles and Iceland) – moderately critical (decreasing), needs further investigation

Lyngen, Northern Norway – moderately critical

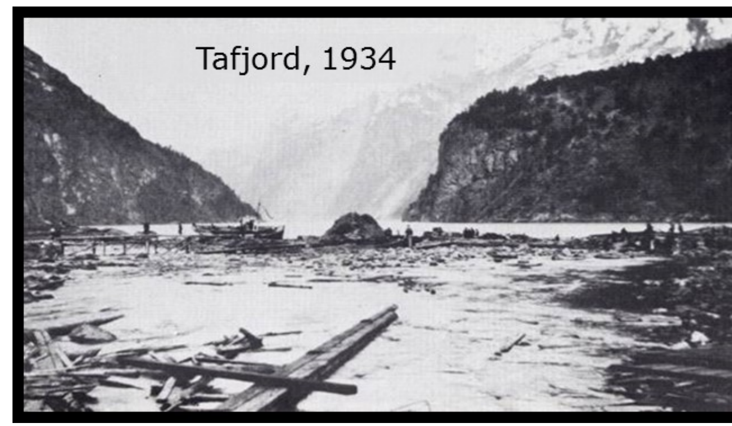
Western Norway fjord systems – critical

Rockslide tsunamis in Norwegian fjords and lakes

~ 2-3 catastrophic events every century



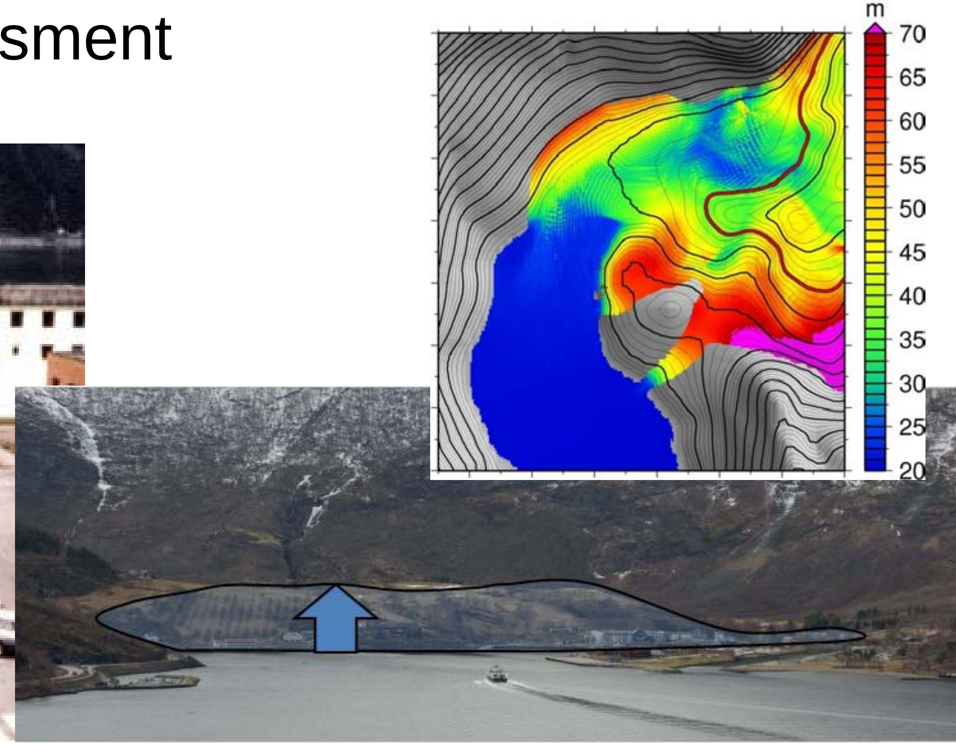
Blikra et al. 2006



Rockslide tsunami studies in Norway

- A long series of studies at UiO and NGI (late 70's →)
- R&D back-calculations; model develoment, validation and understanding
- Consulting; hazard assessment

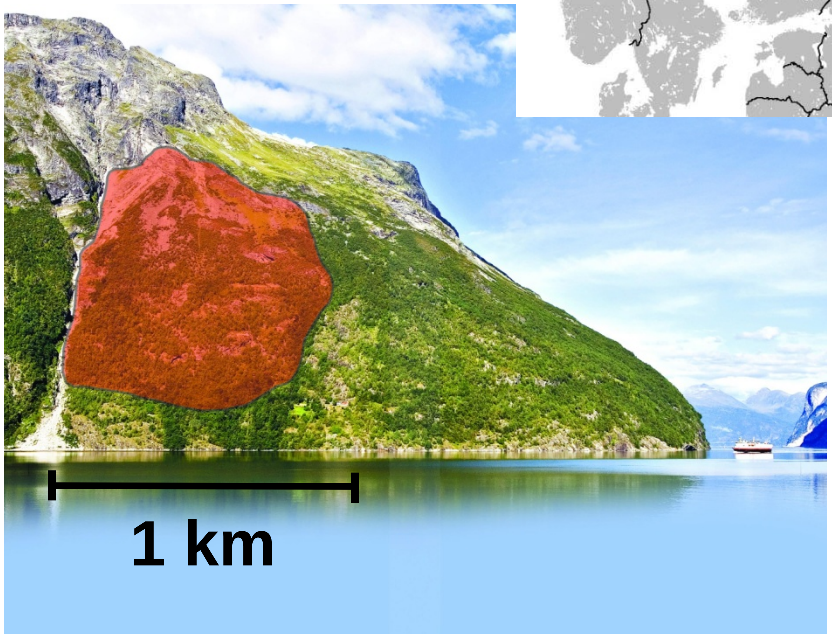
Årdalstangen 1983. Photo: Kurt Johansen, © Årdal kommune

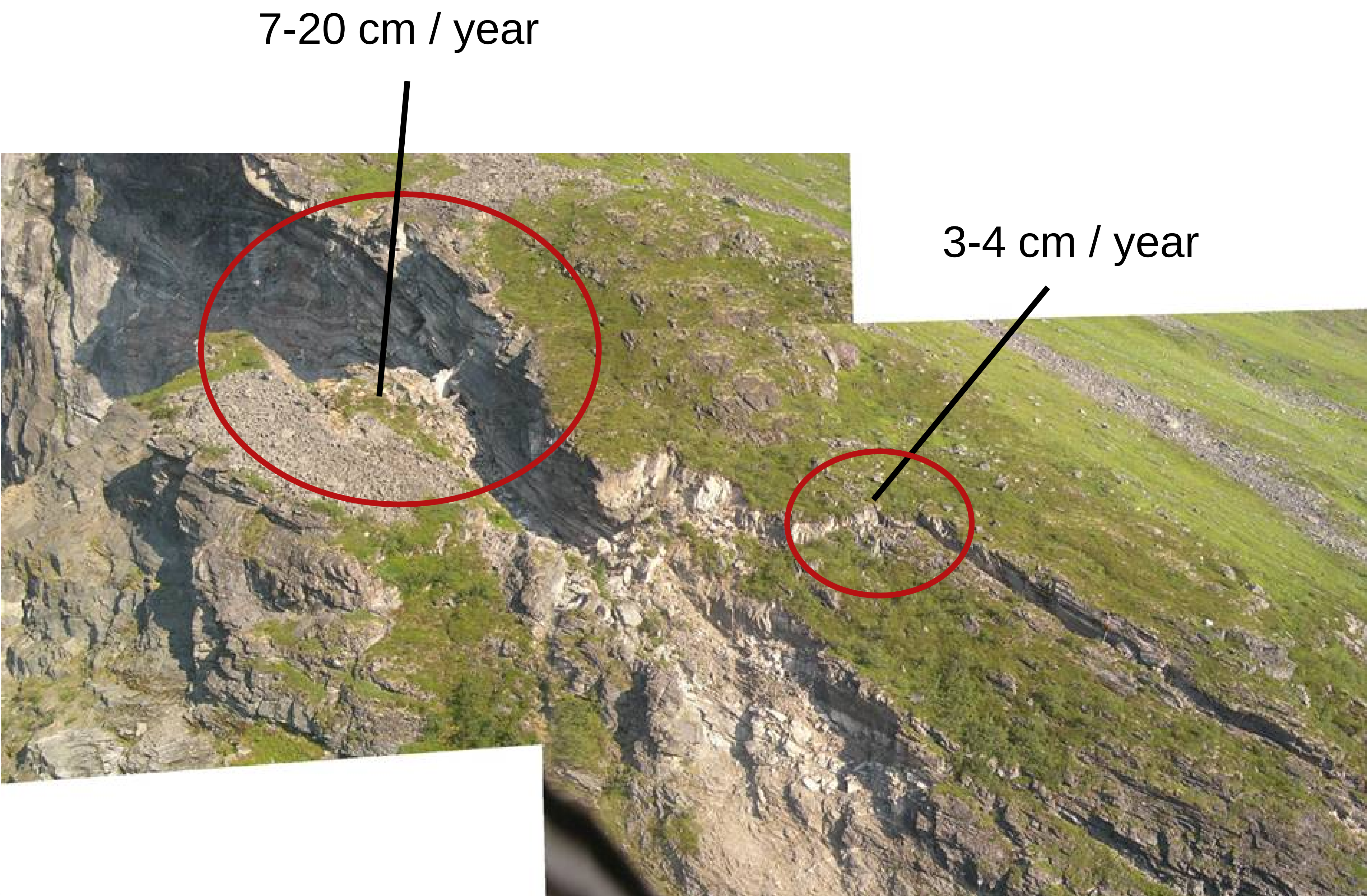


The Åknes-Tafjord project

- Largest volume > 50 Mm^3
- Unstable rock slope

  150 - 900 m.a.s.l
- Large movements/deformations




7-20 cm / year
3-4 cm / year

Historical background

- Fracture discovered by hunters in the 1950's
- 1985→ Monitoring by rod extensometers
- 1991, 1992: Studies initiated by
  Stranda Municipality and the
  Norwegian Natural Disaster Fund
- 2003-2012: CoE International Centre for Geohazards
  - Five partners: NGI, UiO, NGU, NORSAR, NTNU

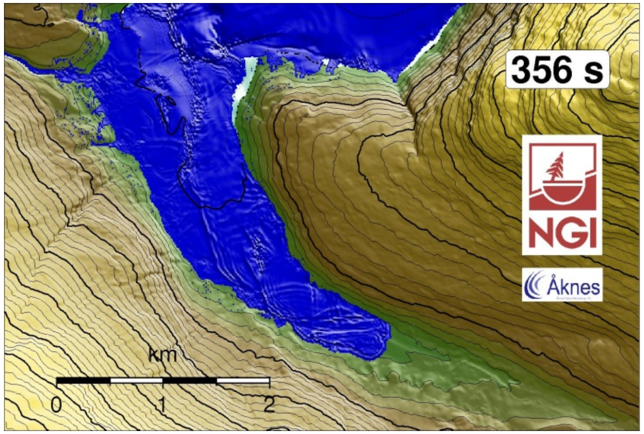
ICG

Åknes/Tafjord-prosjektet

Historical background

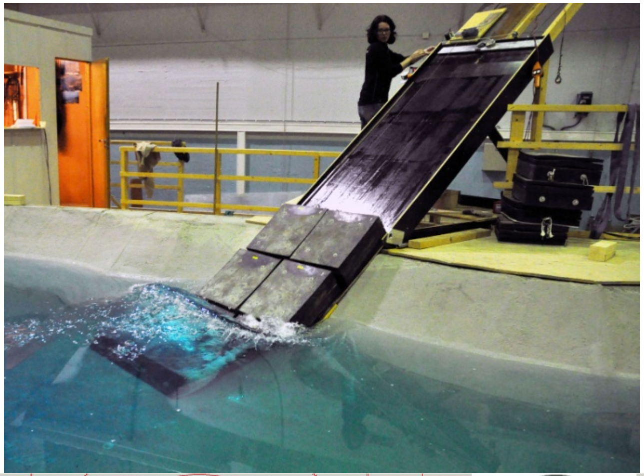
1. 2004: Åknes/Tafjord project established

   - Presently Åknes/Tafjord beredskap IKS www.aknes.no
   - Rock slope monitoring – geo – rock slide and wave dynamics laboratory and numerical studies – risk assessment – mitigation

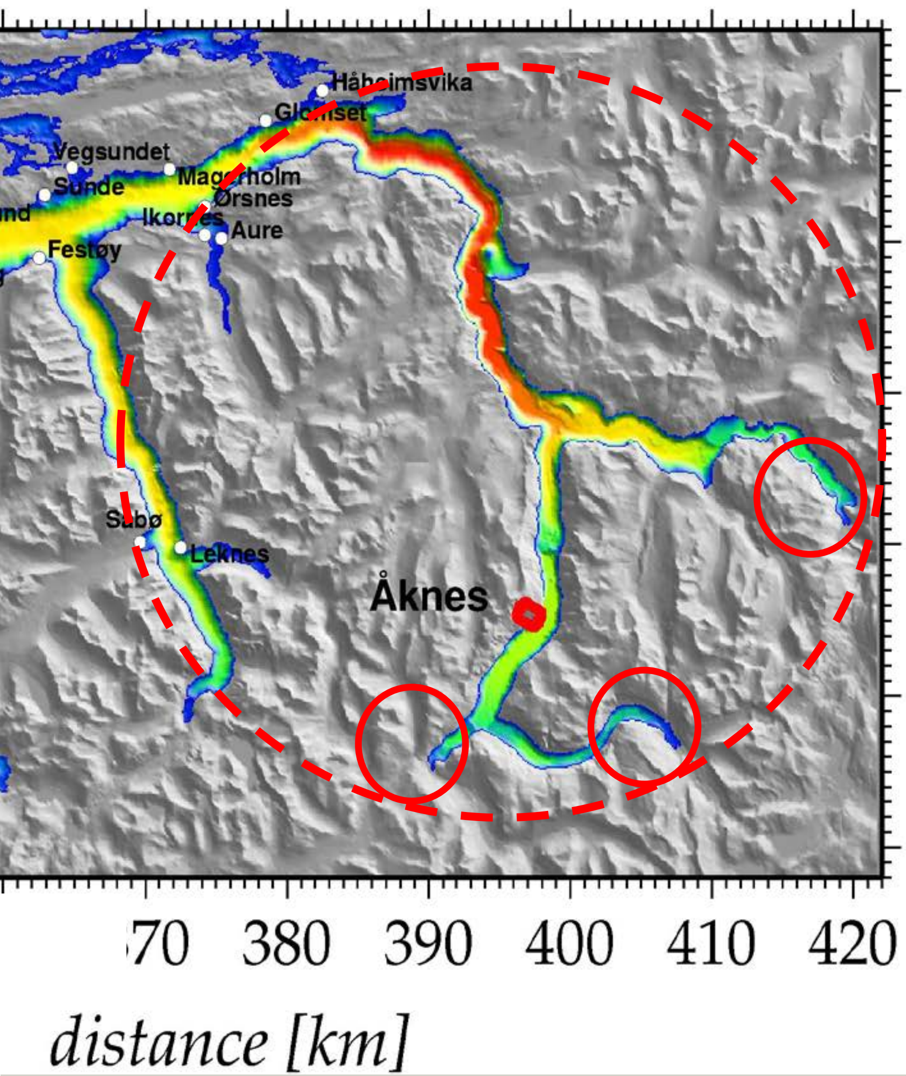


2. 2005-2010: NGI rockslide tsunami consulting project

3. 2011-2014: UiO-NGI-CHL research project granted by RCN-FRITEK: “Laboratory experiments and numerical modelling of tsunamis generated by rock slides into fjords”



Storfjorden



- Narrow fjord with steep hillsides
- Maximum depth more than 700 m
- Fjord heads in the inner part of the fjord are the most critical locations
  - Largest amplification
  - Most people live here
- In summer thousands of tourists
- Arrival times after slide release
  - Hellesylt, 4-5 min
  - Geiranger, 10 min
  - Tafjord, 12 min

Modeling a complex problem

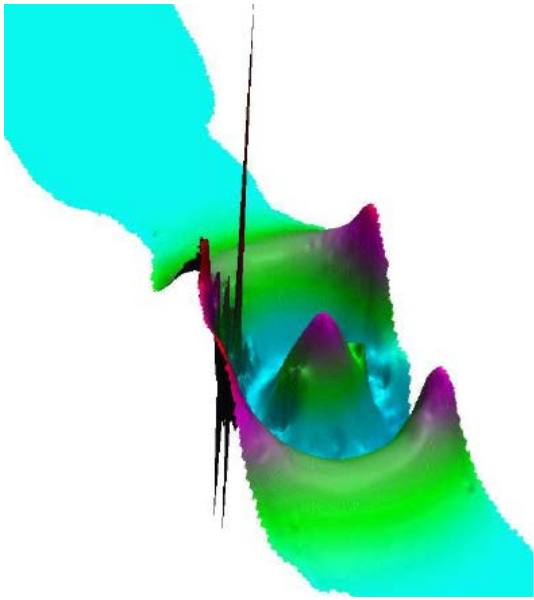
Large volume and high impact velocity

- Nonlinear and dispersive effects

Large bathymetric gradients

Generation phase important

- Deforming (retrogressive) slide or one big block?
- Shape of the slide when hitting the water
- Interaction with water during submerged run-out



Laboratory experiments

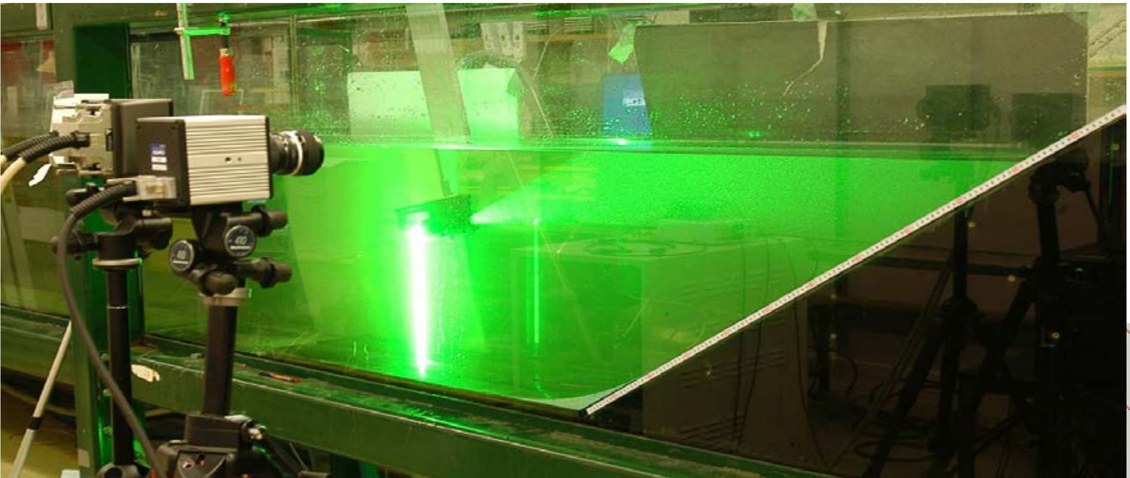
Numerical simulations

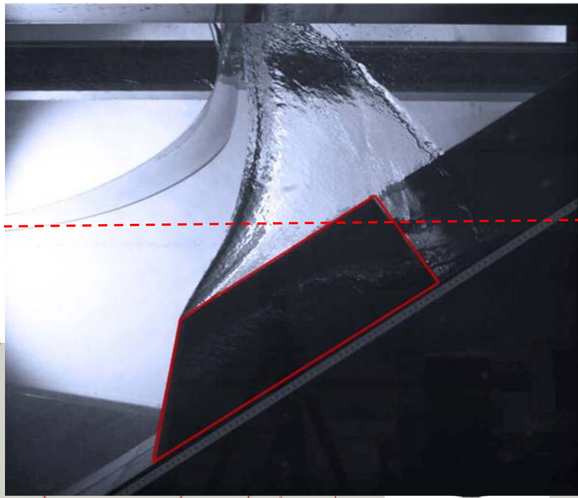
Modeling approach – laboratory experiments

2D and 3D (scale 1:500)

Rounded box slides (idealized)

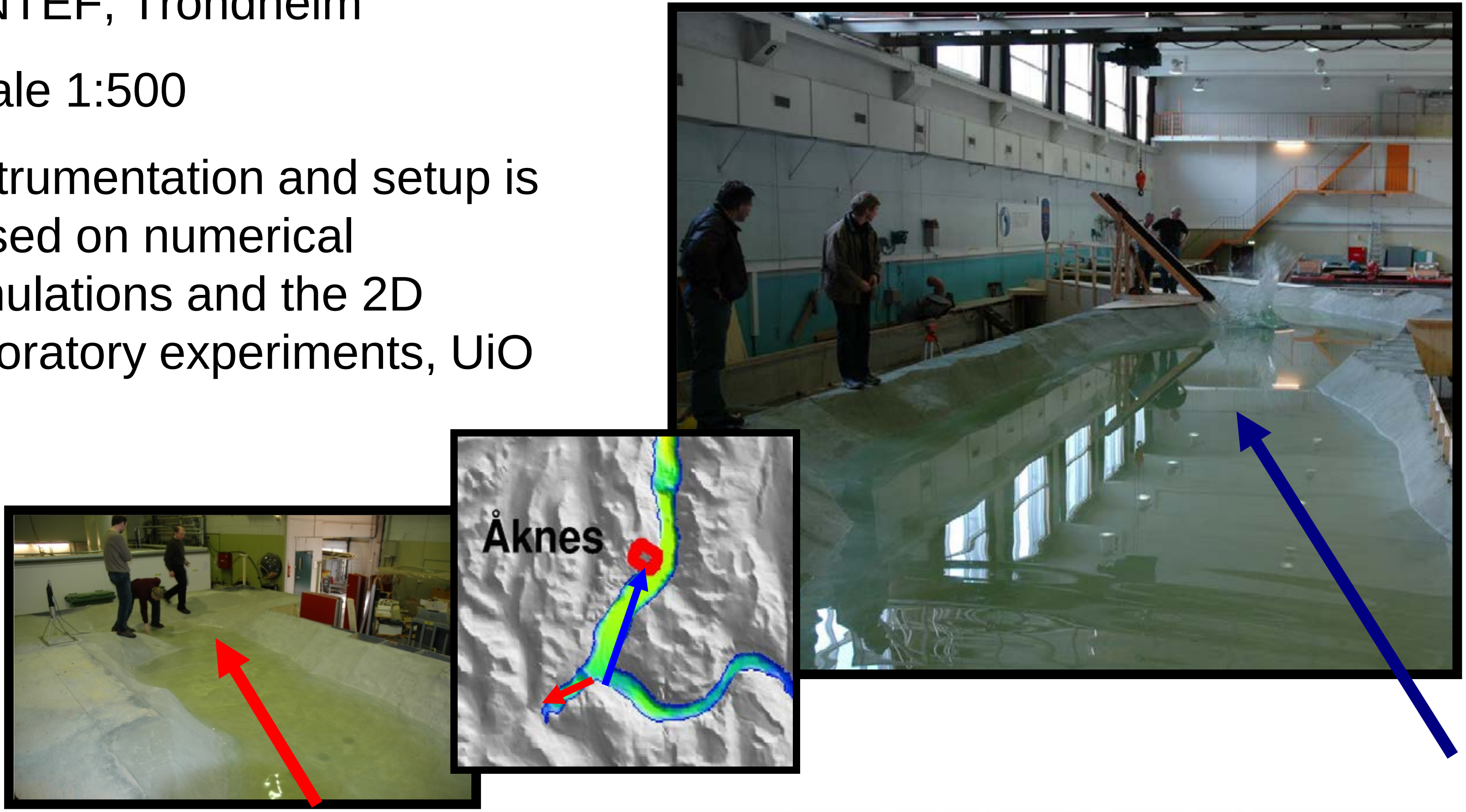
Validation of and input to numerical tsunami models



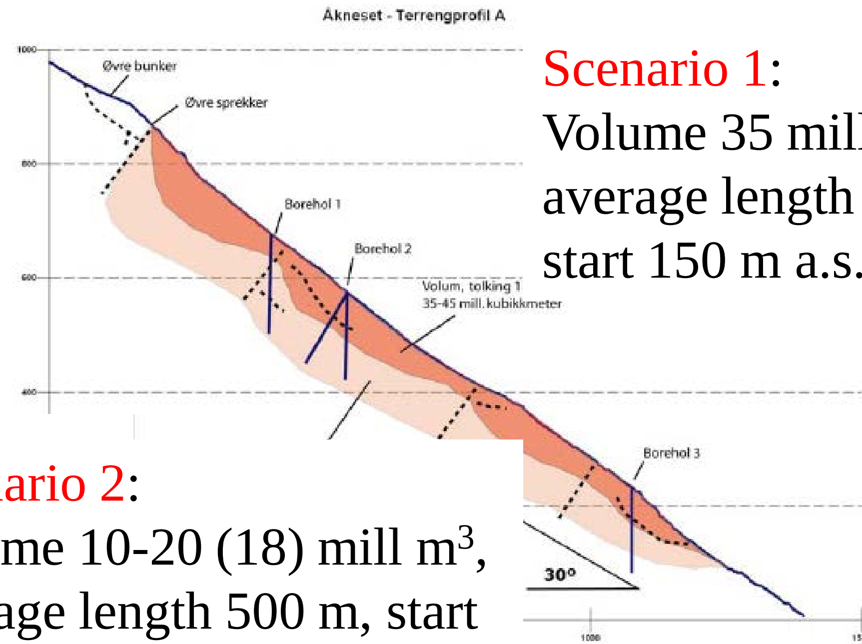


3D laboratory experiments

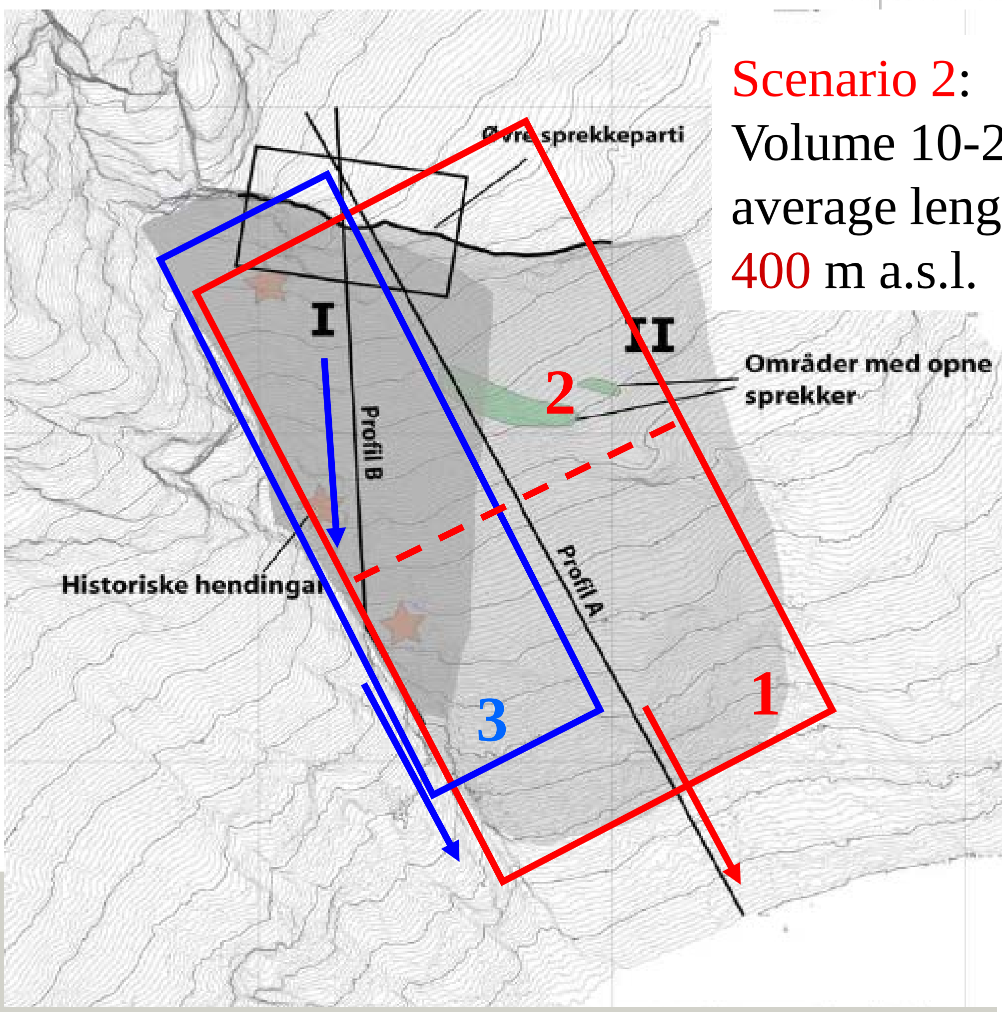
- Coast and Harbour Research Laboratory at SINTEF, Trondheim
- Scale 1:500
- Instrumentation and setup is based on numerical simulations and the 2D laboratory experiments, UiO



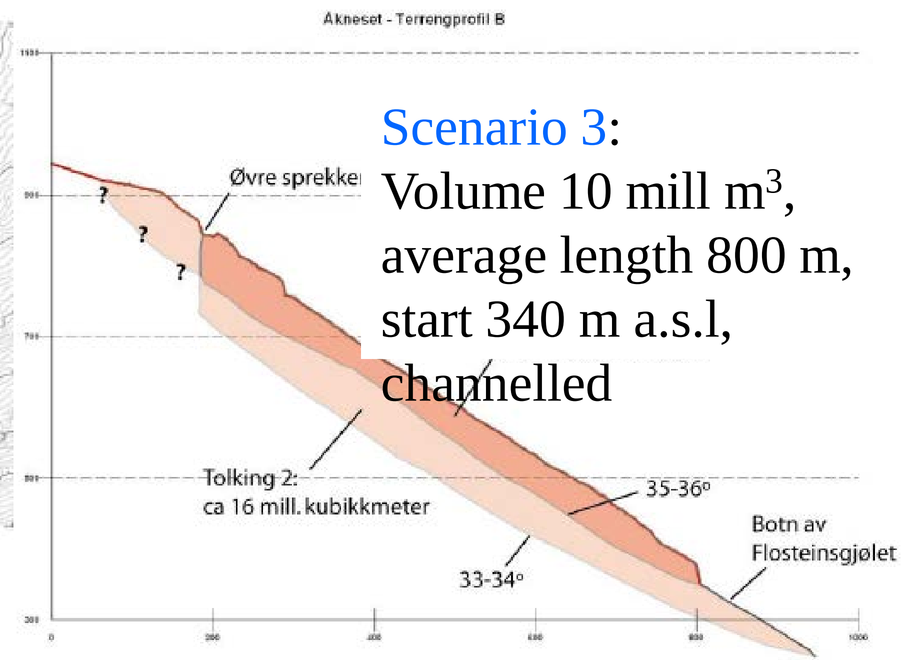
Rock slide parameters



Scenario 1:
Volume 35 mill m^3, average length 1000 m, start 150 m a.s.l.

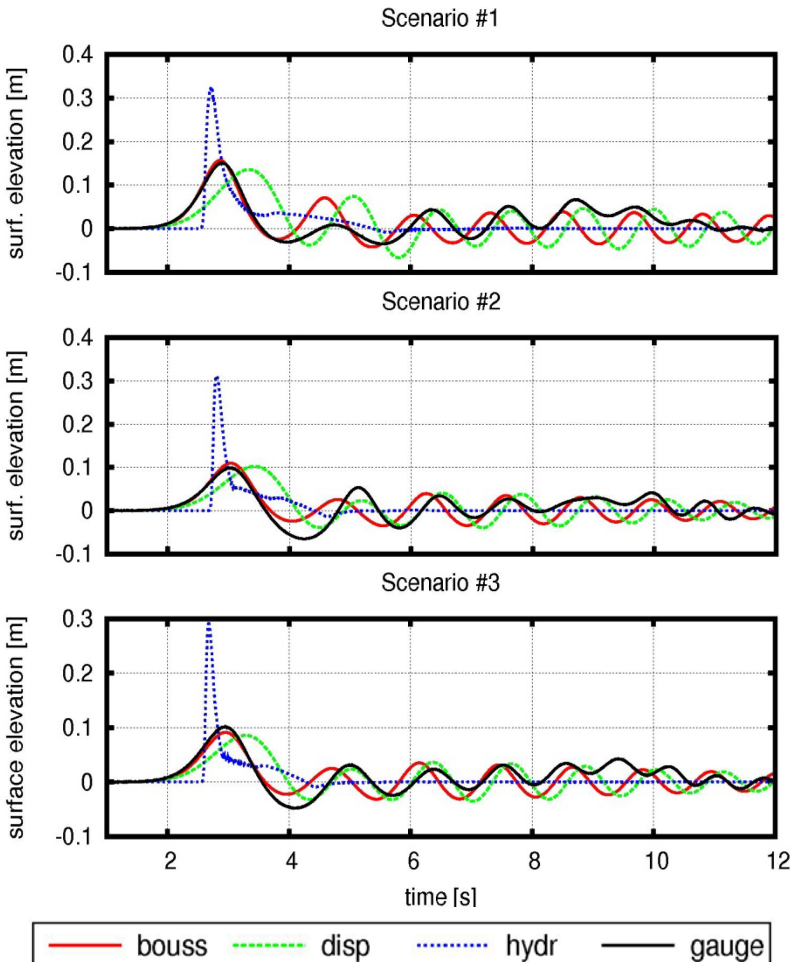


Scenario 2:
Volume 10-20 (18) mill m^3, average length 500 m, start 400 m a.s.l.

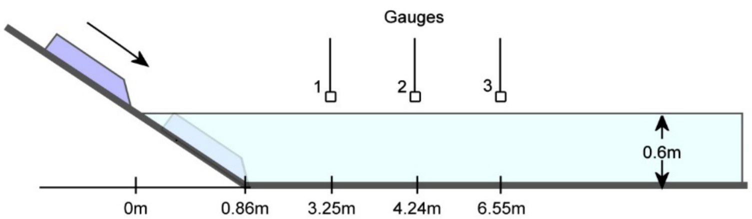


Scenario 3:
Volume 10 mill m^3, average length 800 m, start 340 m a.s.l, channelled

Numerical simulations 2D



- Comparison with the laboratory results at gauge 3
- Different mathematical descriptions
- Boussinesq model reproduce at least the leading wave
- Linear hydrostatic solution overestimates the leading wave



Numerical simulations 3D (2HD)

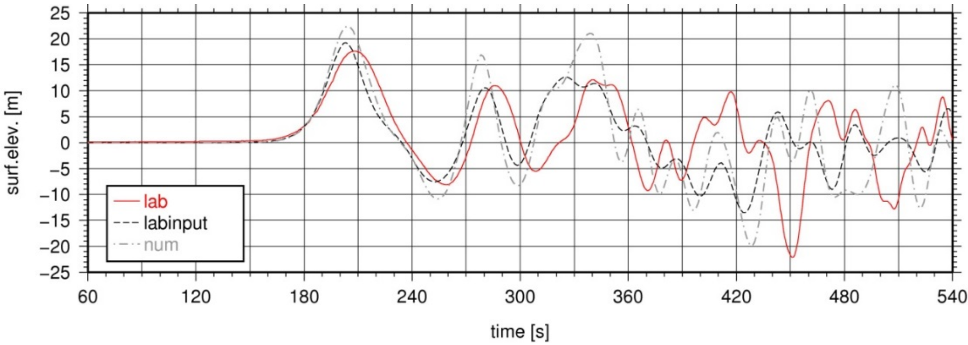
Leading waves well reproduced

Stronger non-linear effects in numerical model, wave breaking more evident

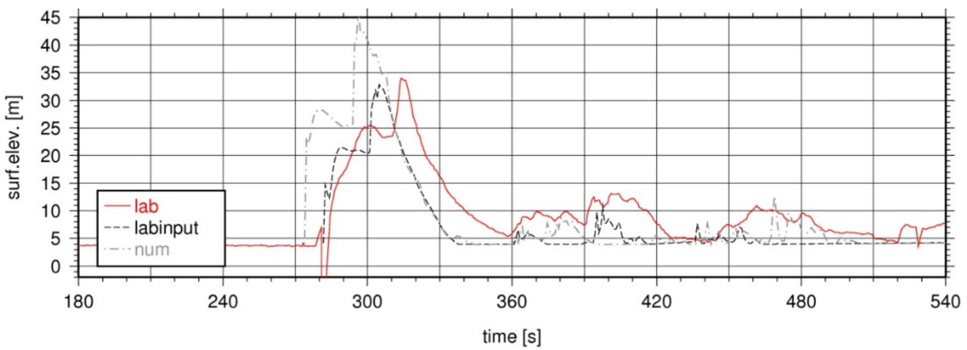
Slower inundation in laboratory experiments

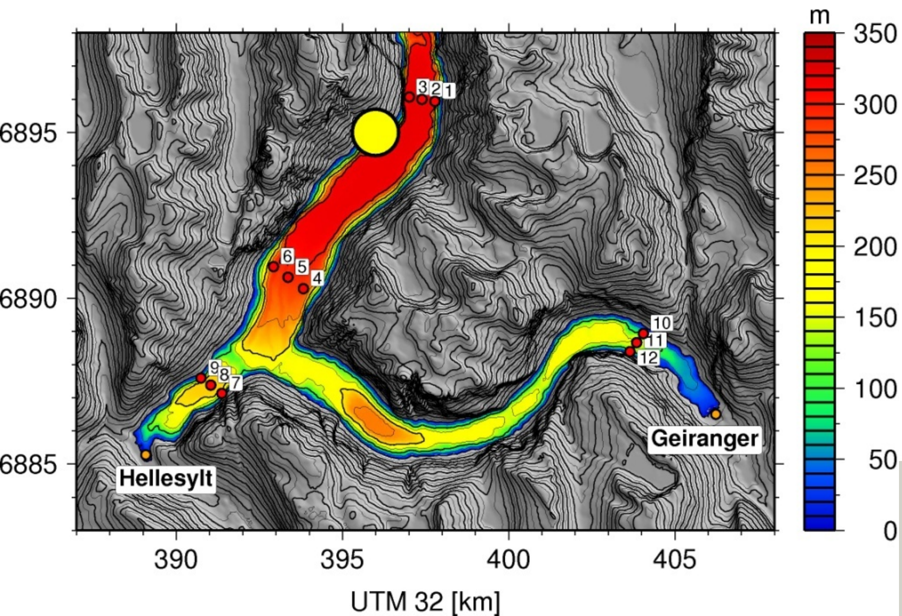
Larger discrepancies for smaller scenarios

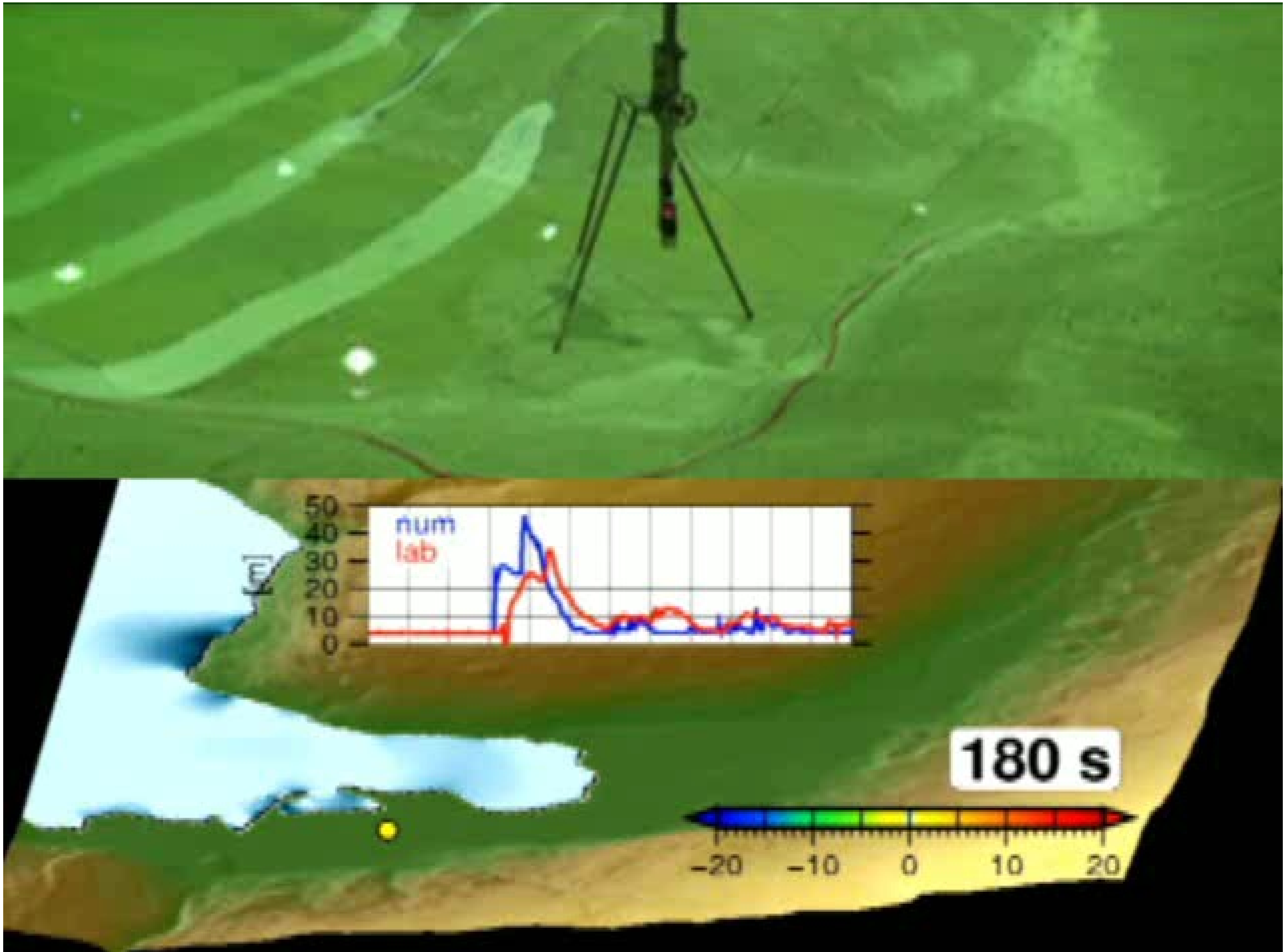
Scenario 1C (54 Mm^3)
Surface elevation outside Hellesylt



Inundation Hellesylt







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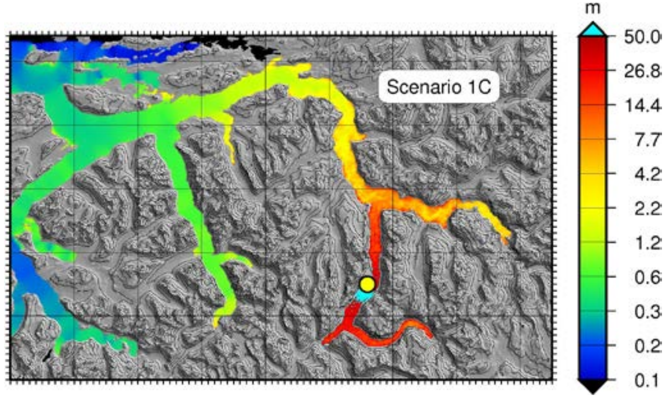
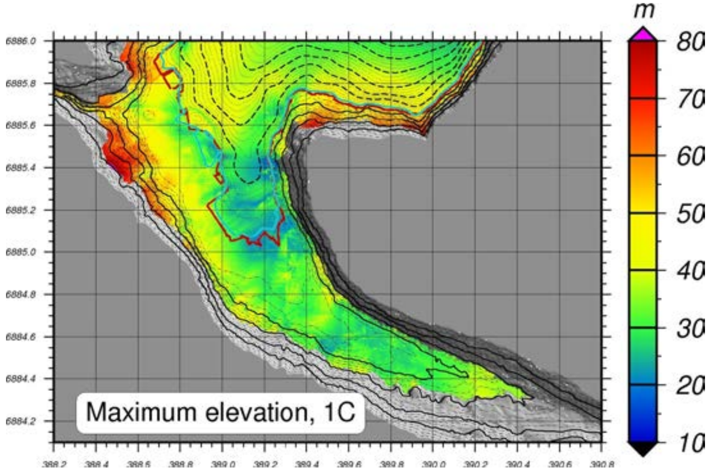
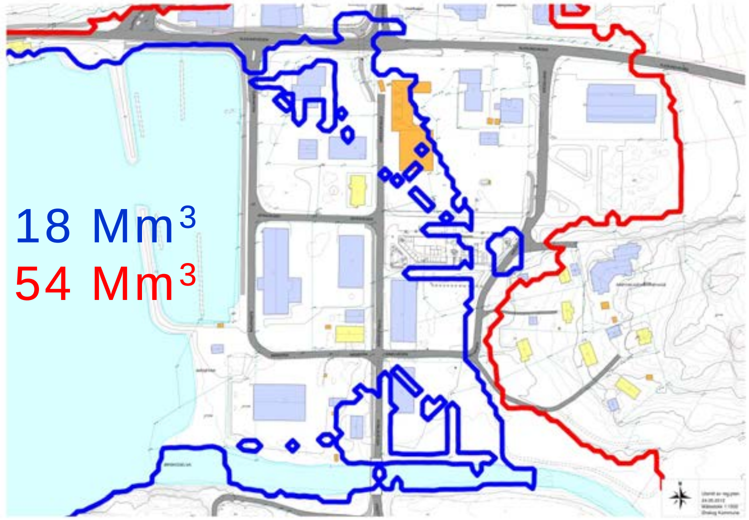
Hazard assessment

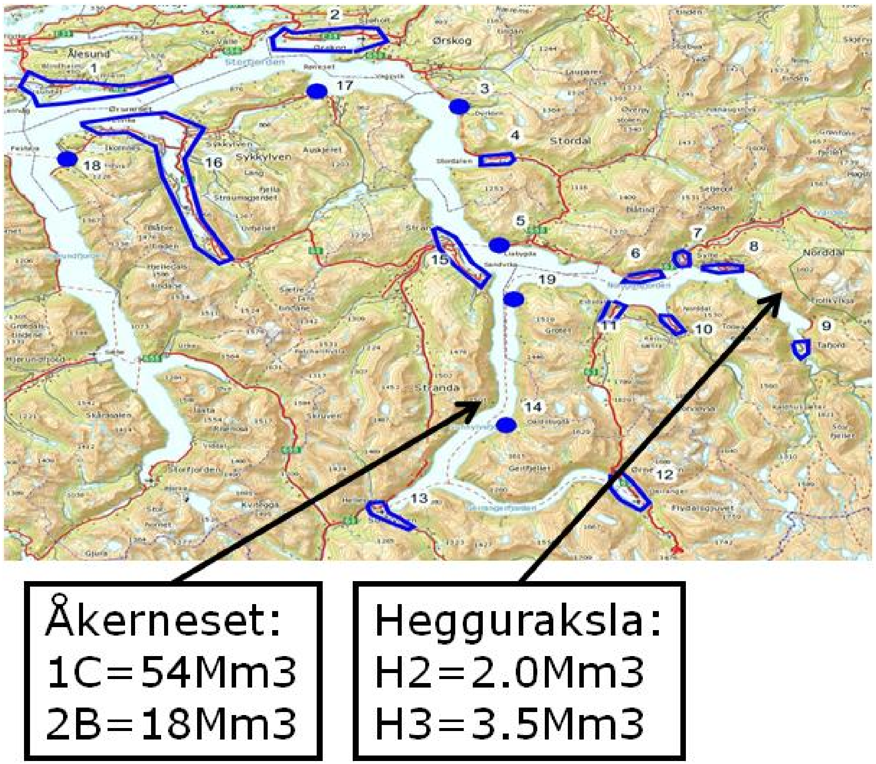
- 2 unstable rock slopes
- Large set of scenarios
  - The larger and less probable scenarios for evacuation
  - Smaller and more probable scenarios for location and design of less critical facilities
- Regional tsunami hazard maps
- Detailed local analyses
  - > 20 locations
  - Inundation heights, flow depths
  - Current velocities







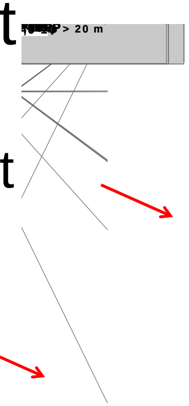
Run-up heights (m)



Location		***Scenarios***			
Name	***no***	***1C***	***2B***	***H2***	***H3***
Dyrkorn	3	5	2	-	-
Eidsdal	11	7	3	-	-
Fjøra	8	5	3	17	20
Geiranger	12	65	25	-	-
Gravaneset	5	6	2	-	-
Hellesylt	13	85	35	-	-
Hundeidvik	18	1	<1	-	-
Linge	6	6	2	-	-
Magerholm	1	2	<1	-	-
Norddal	10	15	6	-	-
Oaldsbygda	14	100	70	-	-
Ørskog	2	6	3	-	-
Ramstadvika	17	3	1	-	-
Raudbergvika	19	18	7	-	-
Stordal	4	8	3	-	-
Stranda	15	6	2	-	-
Sykkylvsfjorden	16	3	<1	-	-
Tafjord	9	13	5	8	14
Valldal	7	8	3	6	10
Vegsundet	1	3	2	-	-
Vika	8	9	4	8	13

Risk assessment

- Rock slide tsunamis affect the entire fjord system or region
- The risk is larger than accepted by the Norwegian Building Act
  - The Act is today altered to open for specified further development in the various hazard zones
- Risk asssessment by event tree analysis
- Evaluations of societal economical impacts



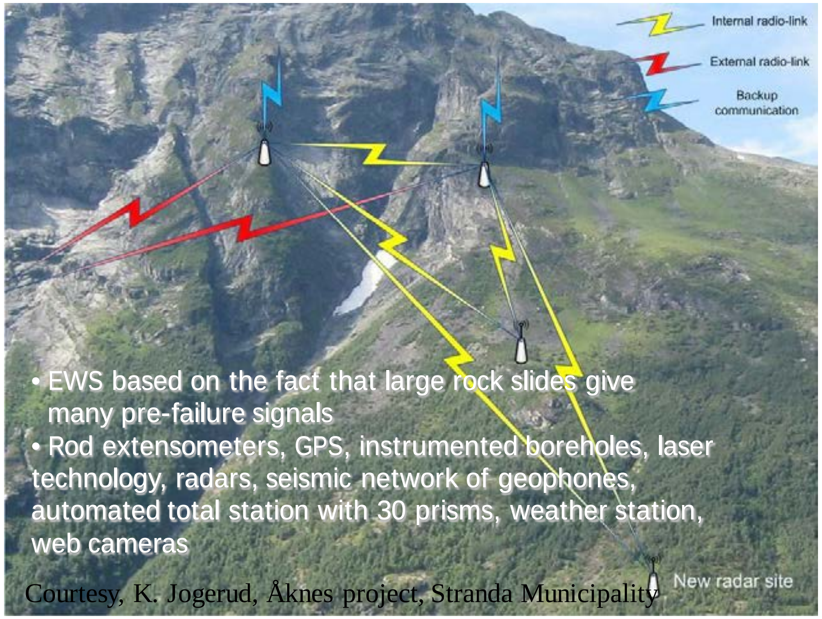
Mitigation measures (1:2)

Inter municipalital preparedness centre established

- ✓ 7 municipalities and the County

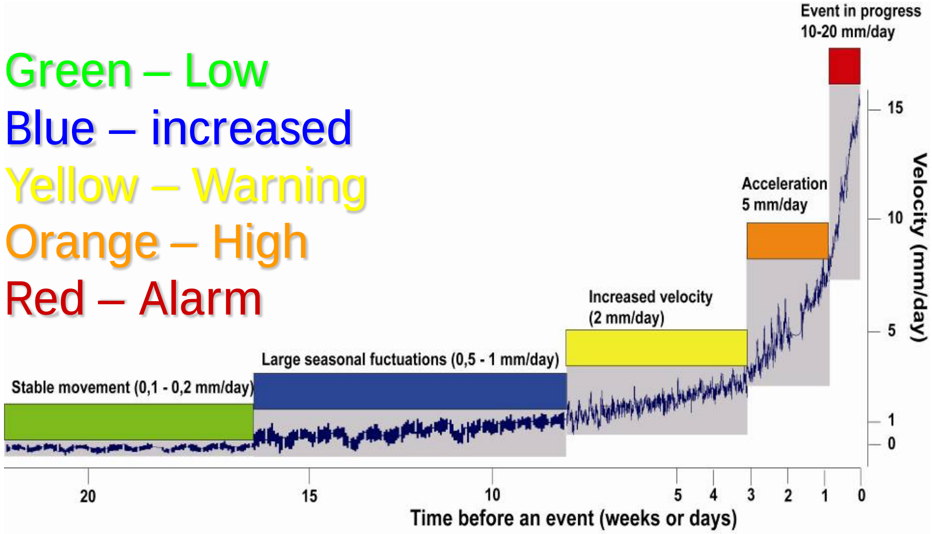
Monitoring of the rock slope

Tsunami warning (> 72 hours in advance)



Courtesy, K. Jogerud, Åknes project, Stranda Municipality

Green – Low
Blue – increased
Yellow – Warning
Orange – High
Red – Alarm



Mitigation measures (2:2)

Landuse planning

Evacuation plans

Emergency exercises

Drainage?

Other suggestions:

- ✓ Fastening or blasting
- ✓ Fill the fjord beneath
- ✓ Environment, ecology, natural heritage

Openness

- Public meetings, media, stakeholders

Nordnes, Lyngen

- Monitoring based on experience from Åknes
- 11 Mm^3 rock slide will cause 10-15 m run-up at Lyngseidet
- Pollfjellet 1810: 14 †

The ongoing UiO-NGI-CHL research project

2011-2014: Laboratory experiments and numerical modelling of tsunamis generated by rock slides into fjords

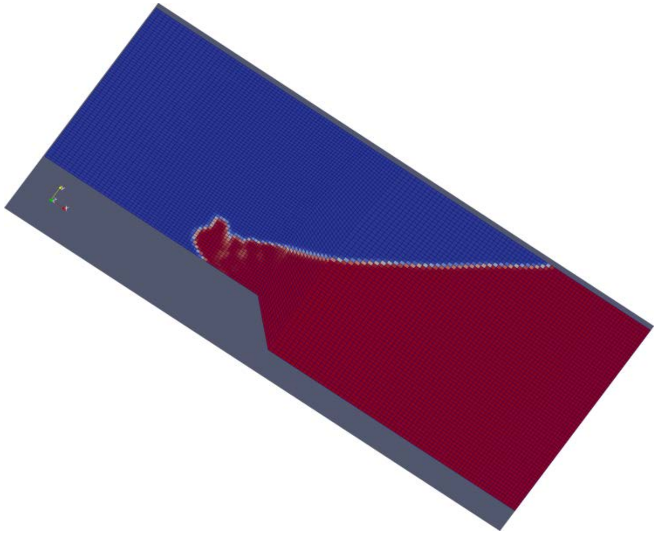
Project manager: Prof. G. Pedersen

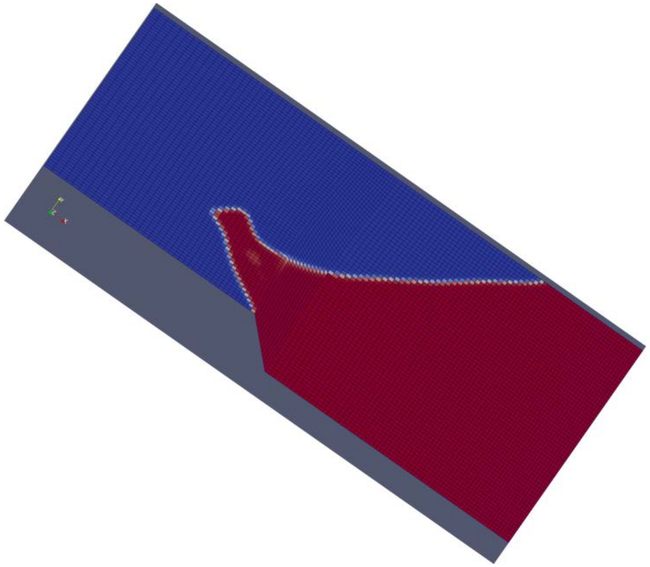
Coupling of 3D Navier-Stokes type models for generation with long wave models for propagation

Laboratory experiments

Rockslide tsunami generation model

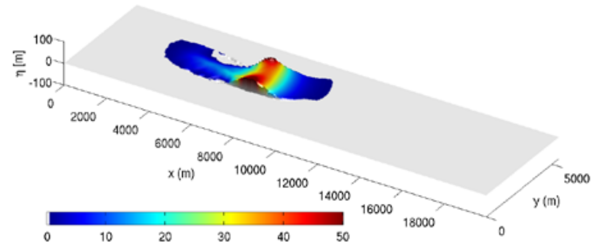
- Different NS solvers tested
- Special features like flow separation difficult to capture reliably (right)
- Runup on facing side may be under-estimated
- Series of spurious effects detected
- Choice of model still open

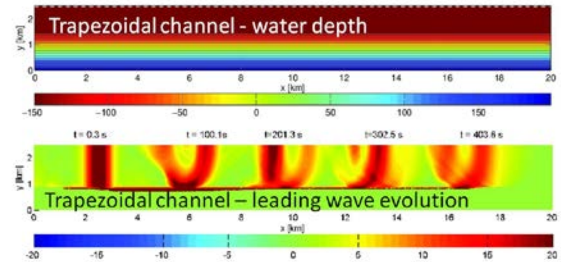


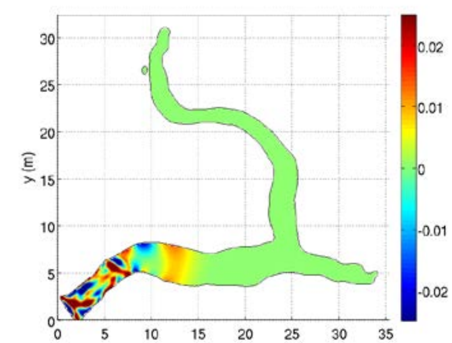


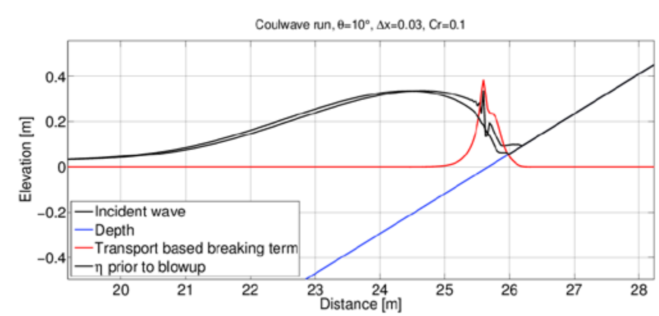
Rockslide tsunami propagation model

- Stability challenged by steep bathymetry and nonlinearity
  - Løvholt et al. (2013) Nonlin process geophys
- Runup on steep sides of the fjord important for propagation
- Trailing waves and edge waves difficult to capture accurately
- Progress on application of the COULWAVE model
  - cooperation with Pat Lynett
- Coupling with 3D Navier-Stokes type models for generation

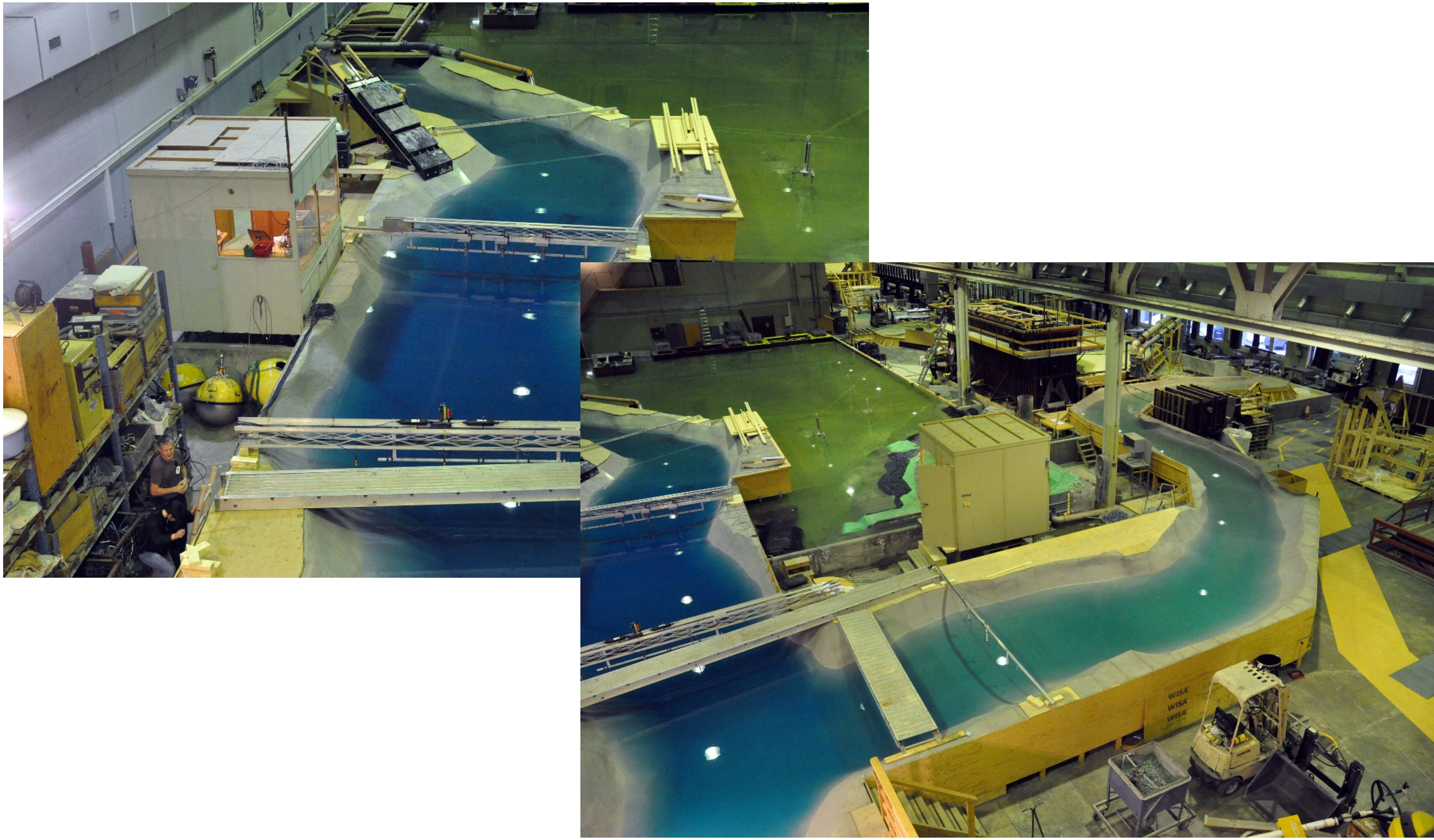








Laboratory experiments

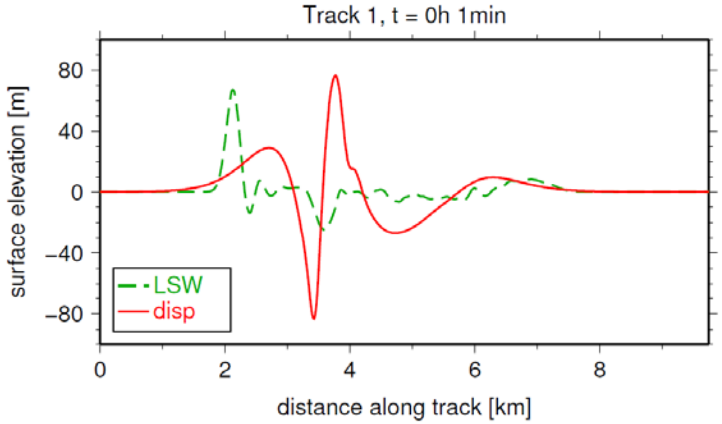


Spin-off problems

- Boundary layers
  - Laboratory experiments and stability analysis
  - Important with respect to scale effects
  - Pedersen et al (2013). Physics of fluids

- Run-up on composite beaches
  - Laboratory experiments
  - Sælevig et al. (2013) Coastal Engn.

- Accumulated dispersive effects
  - Glimsdal et al. (2013) NHESS




Thank you!